Enregistrement scientifique n° : 171
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Aeolian origin of some saline soil stripes in the Senegal middle valley. Morphological and geochemical considerations
Origine éolienne des bandes de sols salés dans la moyenne vallée du fleuve Sénégal.Arguments morphologiques et géochimiques

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In the lower middle valley of the river Senegal, many studies underline that the salt distribution is not related with the actual faint topography or geomorphological units distribution. The lack of logic in the salt distribution is a major constraint for establishment of new irrigated areas. The origin of the salt distribution is here studied for a better understanding of its distribution. A delineation of saline zone was attempted on two sites using an electromagnetic method. The results show that the salinity is distributed as stripes, finging former creeks on the southern bank. On one site, the stripe is intersected by an actual creek bed, indicating that the salt distribution is ancient, related to the former geomorphology, and does not result from a recent remobilization of the marine salt incorporated in the soil.
The chemical facies of the saline stripes was studied on short transects on both site. They exhibits a large variability of chemical facies at small distance. Concentration / dilution process on its own is not enough to explain the variability in the chemical facies, which can only result from the concentration of solid salt particles.

Morphology and geochemistry of these saline stripes are put toghether with the actual saline clay dune (or lunettes) formation in the delta. These dunes are fringing the creeks on the southern bank, under the prevailing winds. They are supplied by saline particles during the dry season due to the aeolian deflation on associated pan floors. This type of salt accumulation is probably responsible for the present distribution of salt in the lower middle valley, and under similar environmental conditions to those observed today in the delta.

Key words : aeolian deposits, saline soils, Senegal middle valley, Senegal.
Mots clés : sols salés, dépots éoliens, moyenne vallée du Sénégal, Sénégal.

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1. Introduction

The development of irrigated agriculture is one of the main objectives defined for the Manantali and Diama dams in the senegal valley (OMVS, 1975). Most of irrigation infrastructures was constructed by the donors as a response to the droughts of the 70s. They are important contributor to food security in the region. However, this development confronts with a large extension of saline soils, existing prior to irrigation, which constitute a major constraint to agriculture, mainly in the delta, but also in the lower middle valley (Fig. 1).

In the lower middle valley, saline areas with abrupt boundaries are generally observed, in contact with non saline areas. Although the soil distribution is closely relationed with the distribution of the geomorphological units, saline zone are observed as well in river bank than in depression. The relationships between topography and soil salinity, between soil and water table salinity, are not close. These specific characteristics of saline areas observed in the lower middle valley leads to the question of their origin, hence to understand the salt distribution, which is the objective of this paper.

2. Site

The Senegal valley was submitted to a recent transgression, which started about 4000 years ago (Nouakchottian) up to Bogué (Michel, 1973). This trangression is responsible for salt incorporation (neutral chemical facies) in the parent material into which the soil sequences were formed (Deckers et al., 1997). The salts have been partially evacuated thereafter and traces of salinity are observed up to 350 km inland. The water table is generally observed between 1 and 4.5 m depth, into a thick sandy horizon attributed to the erosion of Ogolian dunes and sand deposition during the Nouakchottian transgression (Michel, 1973). The chemical facies of the water table confirms its marine origin. However, wide spatial variations of the concentration degree are observed (Loyer, 1989).

Two major geomorphological units are distinguished in the middle valley : river banks, and depression. They are respectively occupated by Typic Xeropsamments and Vertic Xerofluvents (Soil Survey Staff, 1975) locally known as Fondé and Hollaldé (Maymard and Combeau, 1960). The study was carried out in M'Boyo upstream of Podor and Nianga Dieri, along the creek N'Galenka (Fig. 1). The climate of the region is designated semi-arid Sahelian, with a wet season (200 mm rainfall) from July to September, a cold dry season from October to February and a hot dry season from March to June. Temperature averages 24°C in January and 39°C in May.

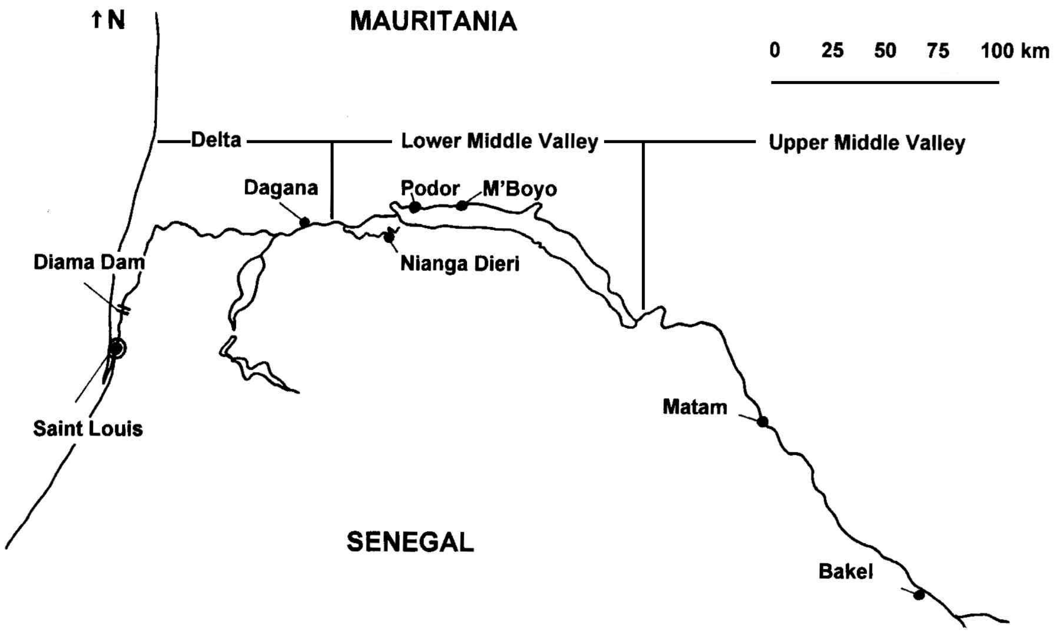


Fig. 1. Location of the study sites in the Senegal valley.

3. Method

Salinity structures delineation

Saline zones were accurately delineated using a portable electromagnetic conductivity meter (Geonics EM38). Vertical measurements were carried out at the soil surface according to a 25 x 25 m regular grid in Nianga Dieri and a 15 x 15 m regular grid in M'Boyo. The calibration of field data measurements with the conductivity of the saturated extract was performed according to Lesch et al. (1992). The sampling allows to determine the structure of the EC_m variable on the sites. An estimate of the sample variogram is given by the formula :

$$g(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z(x_i) - z(x_i + h))^2$$

where N(h) is the number of pairs of points and $z(x_i)$ and $z(x_{i+h})$ are the EC_m value at x_i and x_{i+h}. The kriged map was built from a spherical model and computed from 1269 points in Nianga Dieri (Cunnac, 1996) and 236 points in the M'Boyo site.

N↑

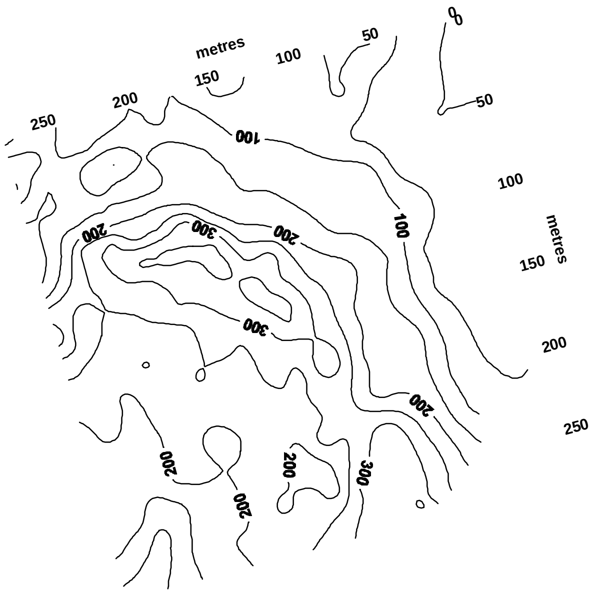
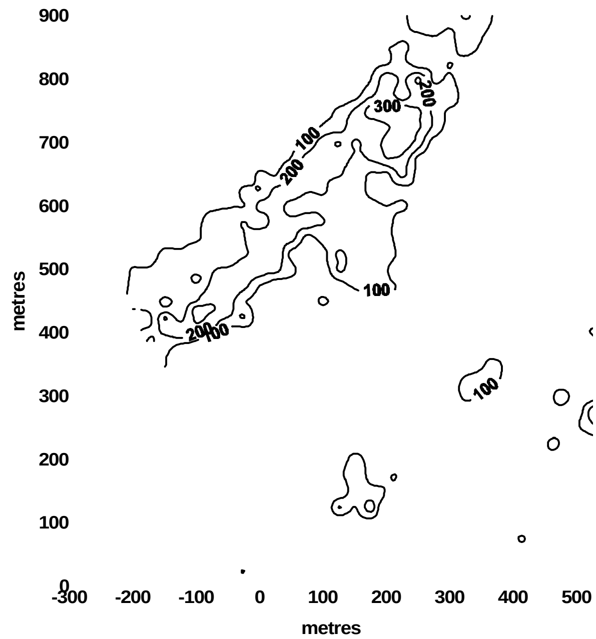


Fig. 2. Electromagnetic conductivity kriged map of M'Boyo↑ and Nianga Dieri ↓.

N↑



Soil sampling

In Nianga Dieri, the sampling was designed so as to maximize the range of salinity on two short transects located thanks to the ECm computed map. 41 samples were taken along 5 borers, at each 0.2 m depth, with a hand-auger. In M'Boyo, 8 pits were excavated and soil was sampled according to a 20x20 cm grid on the soil profiles. Such a sampling was initially destinated to study the relationships between morphological and geochemical characteristics of the soil. This aspect is not developed in this paper.

Solution were extracted by centrifugation of the saturated pastes of soil samples in the laboratory. The major elements were assessed by capillary electrophoresis (NH_4^+, Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, $H_2PO_4^-$, F^- and Br^- ; WATERS, Capillary Ion Analyser) and by atomic absorption spectrometry (Na^+, K^+, Mg^{2+}, Ca^{2+} ; VARIAN Spectra AA). Carbonate alkalinity was determined by potentiometric titration. Only the usual major components were detected and are presented here.

4. Results and discussion

Morphological aspects : The computed ECm kriged maps are presented in fig. 2 and confirm the heterogeneity of the study sites in terms of salinity. In both site, clear saline areas are observed. They exhibit a form of stripe. In Nianga Dieri, the stripe is about 200 m wide, in the NE-SW direction. A 800 m long portion of the stripe appears on fig. 2, but the prospected area was recently increased and the total length of the stripe is over 3500 m. In M'Boyo the stripe is curved, 50 m wide and 300 m long in the prospected area. Similar saline stripes were revealed by other prospection in the lower middle valley, for example in Ouromadiou, Nianga, Pont Gary, Guia (Gascuel-Odoux and Boivin, 1994, Laval, 1996). This structure appears therefore representative of the salt distribution in the lower middle valley.

The N'Galenka saline stripe delineation has been overlied to the main geomorphological units using aerial photographies. It appears that the salt distribution can be relationed with the trace of a former creek not easely perceptible in the field. However, the relationship between the salt distribution and the trace of this former creek is not so close. The saline stripe is fringing the former creek bed on the southern bank. It also appears that the saline stripe is intersected by the actual N'Galenka creek bed, indicating that the salt distribution existed prior to the actual N'Galenka. These observations suggest that the actual salt distribution is linked to the former geomorphology, and does not correspond to a recent remobilisation of the salt. Similar observations, concerning the distribution of the salt in relation to a former creek, were made in M'Boyo.

Geochemical aspects : The total concentration of extracted solution varied largely. The saturated pastes are near the equilibrium with respect to calcite (calcite nodules are frequently observed in the soil) and under saturated with respect to current salt like gypsum, mirabilite, thenardite and halite. Fig. 3 shows that spatial changes in the chemical facies are observed along the selected transects in both site. The chemical facies evolves from chlorurated sodic to sulfated calcic and magnesian. As the changes in the chemical faciès of the solution are suspected to be a function of the concentration, data were sorted according to the chloride amount, which is supposed to evolve as a conservative tracer. Therefore concentration diagrams were built using Cl^- to estimate the concentration factor of each solution. On the concentration diagrams, the point line up according to straight lines approximately parallel to the concentration factor. Each line correspond to a chemical facies, which can be Na/Cl, Na/SO4, Mg/SO4…This characteristic is particularly exhibited on the M'Boyo site, but also appears in the sampling points from the Nianga Dieri site. So, we can advance that the chemistry of the saline stripes is characterized by a large variability of facies at small distance.

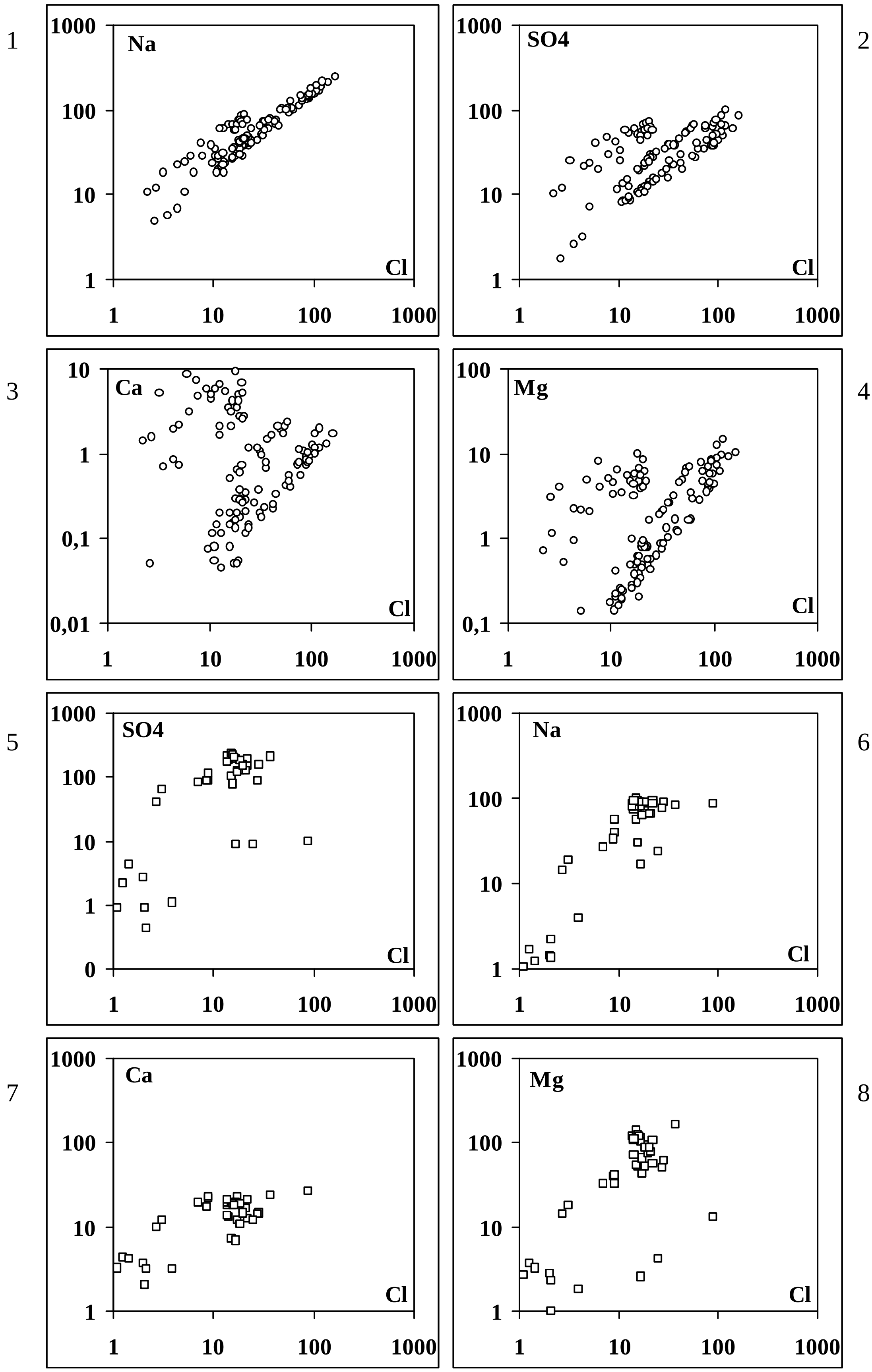


Fig. 4. Concentration diagrams for M’Boyo (1-4) and Nianga Dieri (5-8)

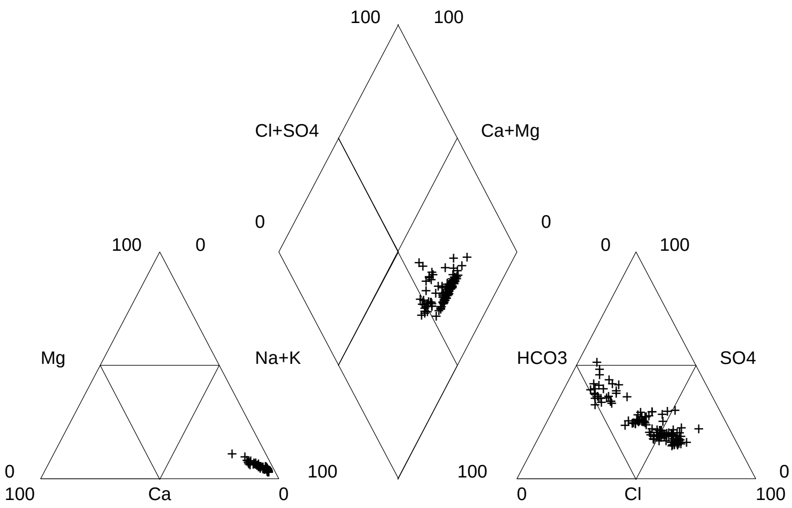


Fig. 3. Chemical facies illustrated by Piper diagram.

Each chemical facies evolves by concentration / dilution process, which is responsible for the linear distribution of the points in the diagrams.

These results contrast with those classically obtained on sites where the salinity results from the concentration of one type of water with a given chemical facies. Such variations in the chemical facies cannot result from the concentration of the same solution. Only the spatial concentration of solid salt particles can produce such a variability in the chemical facies.

Actual observation in the delta

The morphological and geochemical aspect of these saline soil stripes can be put together with the actual clay dune formation in the Senegal delta, and described by Maymard (1952) and Tricart (1954). The clay dunes develop by seasonal deflation from the pan floor under the saline conditions. As the pan dries, salt concentration increases, inducing the mud to floculate to silt and sand size particles which are then vulnerable to wind transport from the pan floor. The wind deflation results in clay dunes formation from the accumulation of these particles under all the obstacles (mangrove, dikes) and around the pans ((Lunettes) Hills, 1940). Most of the clay dunes exhibits therefore a linear aspect fringing the creeks occupated by the residual mangrove forest, under the prevailing winds, hence on the southern bank. The type of wind-moved salt varies during the season. It mainly correspond to gypsum at the beginning of the dry season, and terminal salt like halite at the end of the dry season, when the soil are more concentrated. This scheme of salt distribution match with the observations made on morphology and chemistry of the saline areas in the lower middle valley.

5. Conclusion

In the lower middle valley of the river Senegal, the salt is frequently distributed as stripes. In the two presented cases, the stripes range between 50 and 200 m wide and 300 and 3500 m long. These stripes are not related with topography or soil and geomorphological units distribution. In contrast, they can be relationed with the former geomorphology, and particularly with the former creeks, which saline stripes are fringing on the southern bank. Therefore, the saline stripes does not arise from a recent remobilisation of the salt. From a chemical point of view, they exhibit a large variability of facies at small distance; each chemical facies undergoes the effect of concentration / dilution. This type of salinity is not standard and cannot result from the evaporation of one type of water but from the spatial concentration of solid salt particles.

The morphological and geochemical aspect of these saline stripes, on the other hand, can be relationed with the actual clay dune formation in the Senegal delta. We can therefore advance that environmental conditions similar as those actually observed in the delta, favouring the aeolian deflation and the clay dune formation, were responsible for the salt distribution, which persists up to now in the lower middle valley.

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